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Introduction

The Foerster Rivet Check system is an instrument designed to detect cracks under installed fasteners in relatively thin layers of an aircraft skin. Its operation is based on a rotating self-nulling eddy current probe. This probe, combined with a dedicated laptop computer and data acquisition and signal processing software provides a relatively easy-to-use means of detecting fatigue cracks. The software enables one to centre the probe over a rivet head easily and any defects detected are displayed on the computer screen, together with an indication of relative size and location. Individual test results may be stored for later analysis. A complete description of the instrument may be found in Ref 1.

It is claimed that, with nonferrous rivets, the system can detect cracks as small as 0.020" under a 0.040" first layer, 0.040" under a 0.040" second layer and 0.100" under a 0.040" third layer . The test head can be adjusted for both liftoff and fastener head diameter. The system can be configured for optimum detection in first, second or third layer with thickness ranging from 0.040 to 0.080". The Foerster Rivet Check test head is shown in Figure 1.

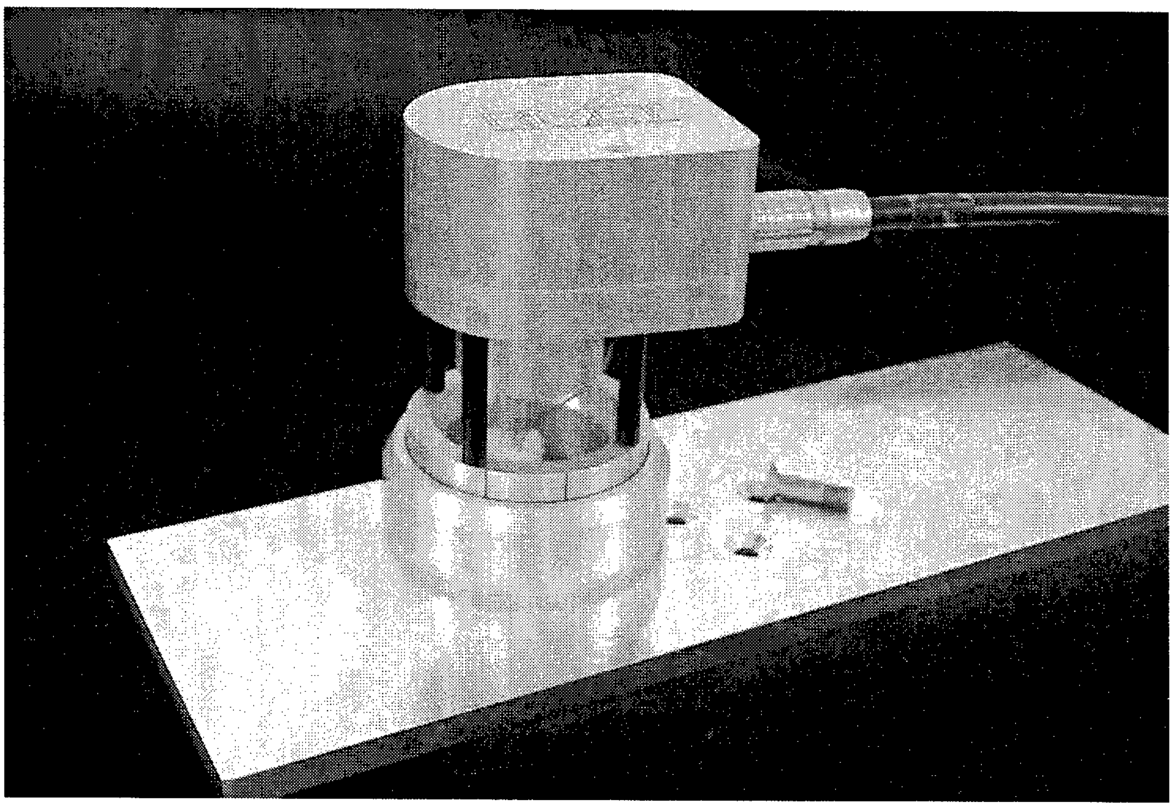


Figure 1 - The Foerster Rivet Check Test Head

To evaluate the performance of the Foerster system for potential use by the Canadian Forces, a unit was loaned to the Air Vehicles Research Section by the manufacturer and a series of inspections to determine the ability of the Rivet Check to detect the presence of known cracks as described below was performed.

Test Specimens and Procedures
(1) QETE POD Specimens

For an initial evaluation of the ability of the Rivet Check system to detect cracks of a wide range of sizes, it was decided to inspect an existing set of 30 test coupons that had been manufactured for and used in previous POD studies. Each coupon consisted of three 0.24" dia holes drilled in aluminum plate and countersunk as indicated in Figure 2. Cracks were generated in a given coupon at one of three different depths (bottom of countersink, mid-bore, faying surface). The cracks, ranging in size from 0.008" to 0.200", were generated by tensile fatigue loading of the coupons, such that the propagation direction was normal to the principal stress axis resulting in the flaws being located 180° apart. The geometry of the holes and depth of the flaws in the hole is shown in Figure 2. The method of preparation and the dimensions of each crack are well-documented in Reference 2.

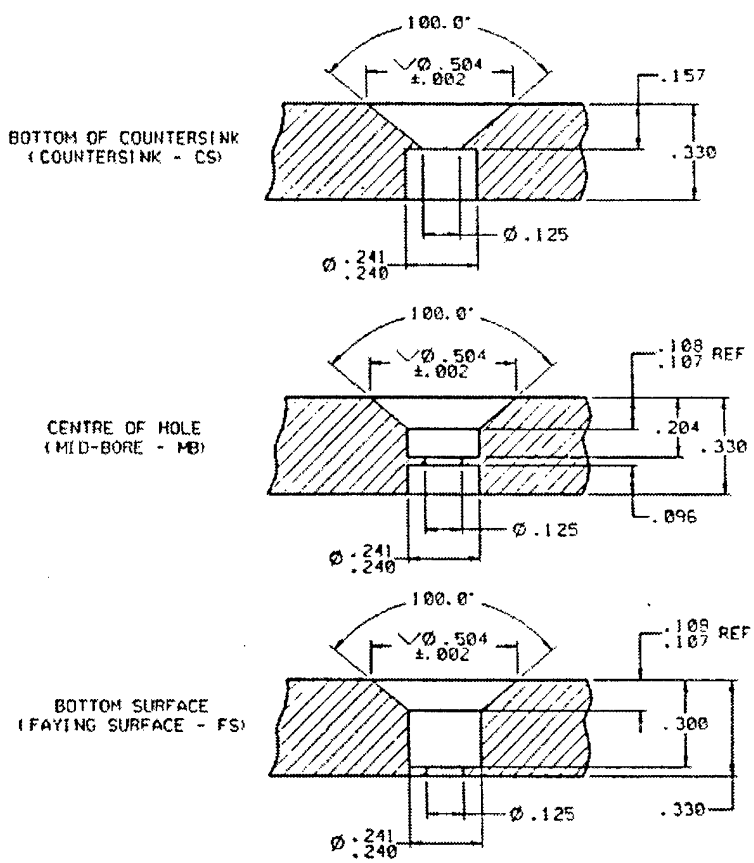


Figure 2 - Geometry of holes and flaw locations.

Flaws located at the bottom of the countersink are nominally 0.10" deep with some extending to the surface, well within the stated detection limits of the RivetCheck.

Although the mid-bore and faying surface cracks are located at depths much greater than this limit, turning each specimen over and inspecting from the bottom surface provided a large number of surface cracks and cracks approximately 0.10" below the surface (mid-bore). These were used to evaluate the ability of the system to detect cracks per se.

To determine the effect of their presence or absence on crack detection, steel and titanium fasteners were machined to a length of 0.330" so that the end of

their shaft was flush with the surface of the coupon. These could then be inserted and removed from the holes without interfering with the rotating eddy current probe on the bottom surface.

When inspecting with the Rivet Check, the user must pre-select and adjust the test head for the thickness of material through which eddy current must penetrate to reach the suspected defect. The system then automatically adjusts the frequency used and calculates a probe scan radius which is set mechanically. This feature is used primarily for inspecting different layers in lap joints. Four different depth settings are available: top layer (60 kHz), 0.040" (10 kHz), 0.063" (4.5 kHz) and 0.082" (2974 Hz)

Several inspections were performed on each hole of the sets of coupons having cracks at one of three different locations - bottom of countersink, mid-bore, faying surface (CS, MB, FS respectively). Each was inspected at each of the four pre-set test depths available with the system (a) without a fastener, (b) with a titanium fastener and (c) with a steel fastener. When inspected from the top surface (CS flaws), the Rivet Check rivet head diameter was set to 0.50" ; when inspected from the bottom surface (FS and MB flaws), it was set to 0.25".

(2) Lap joint inspections

A lap joint specimen (NRC MSD 504) produced in the Structures, Materials and Propulsion Laboratory of NRC was used to determine the ability of the Rivet Check system to detect second layer cracks in lap joints. This sample, shown in Fig 3, is approximately 4" x 8" and is comprised of two layers of 0.040" aluminum held together by three rows of eight rivets on one-inch centres. The first row of fasteners is 0.5" from the edge of the top layer. The specimen had been stressed in the laboratory under controlled conditions to produce fatigue cracks. Holes 4, 5 and 6 in the first row have large second-layer cracks clearly visible on the back surface. There are no cracks in the second row but holes in the third row are linked by a relatively large multiple site damage crack, part of which is shown in Fig 4. Each of the holes in this specimen was inspected using the Rivet Check at each of its four depth settings.

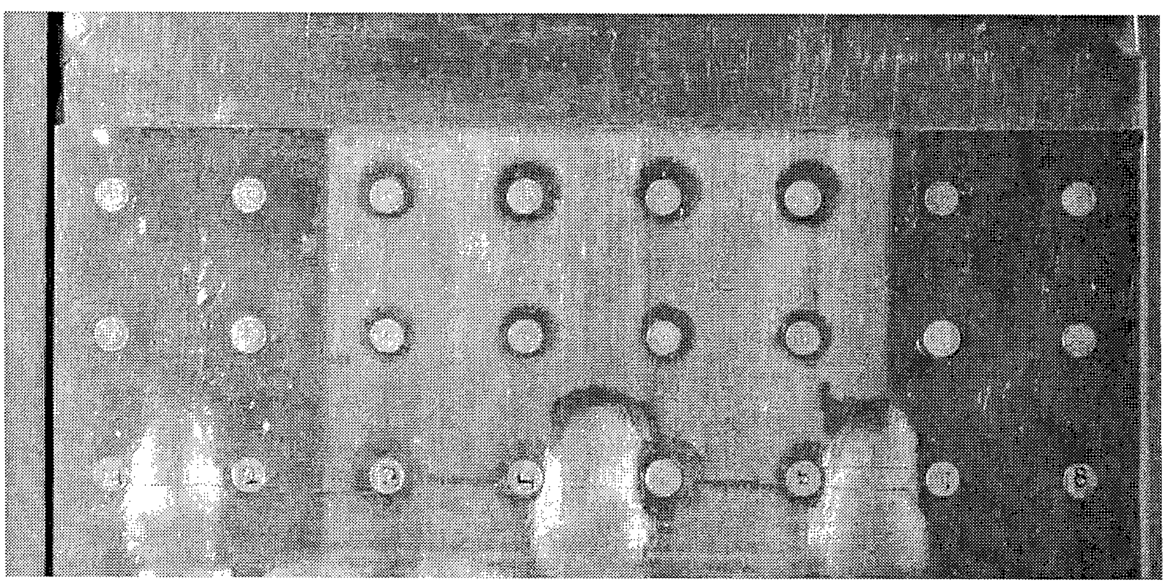


Figure 3 - Lap Joint Specimen MSD504

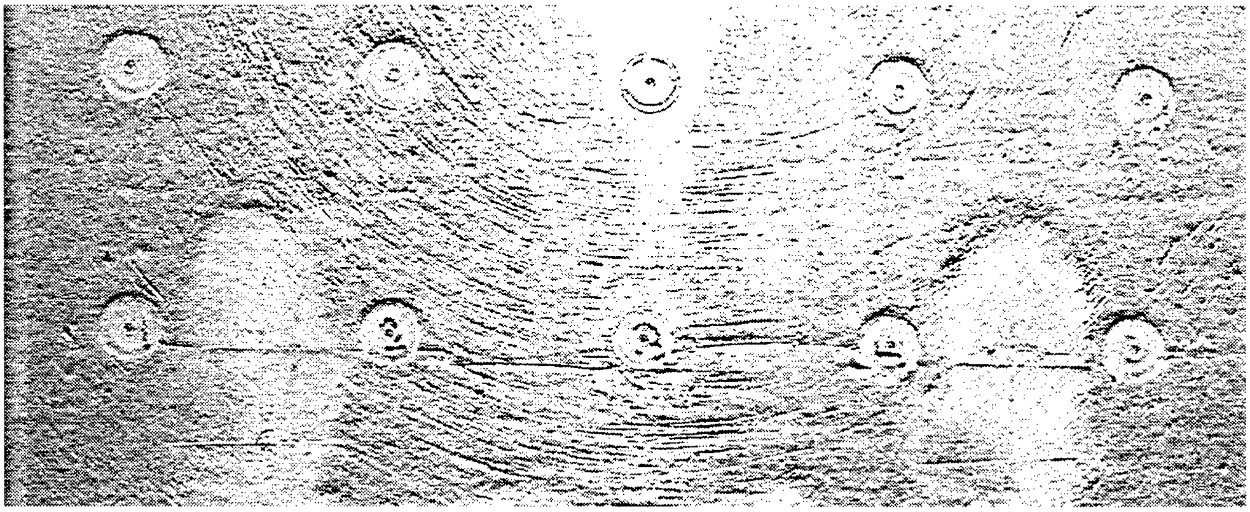


Figure 4 - Image of MSD Crack

Results and Discussion

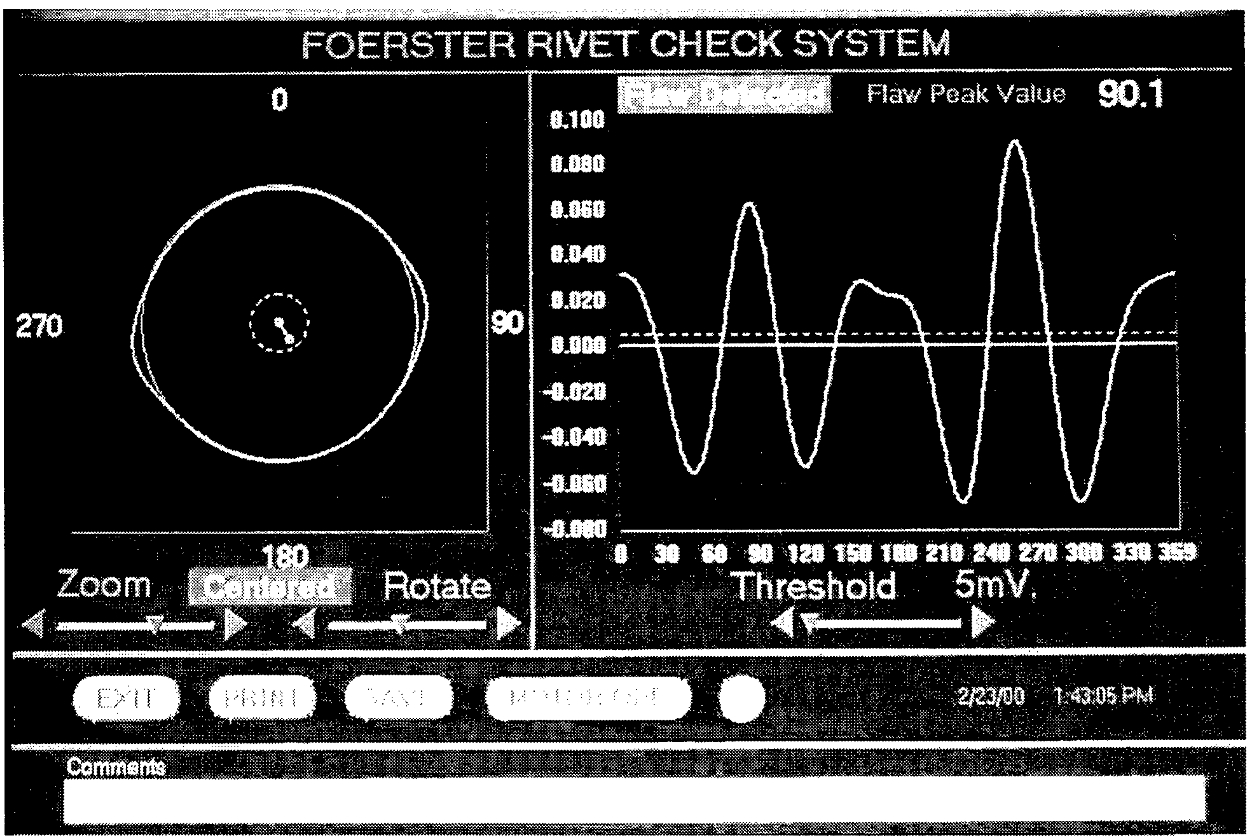


Figure 5 - Rivet Check System Display

An example of the display produced by the Rivet Check system is shown in Figure 5. The left side of the screen is a guide for centering the test head on a rivet. Detection of flaws generates a display similar to that on the right side of the screen. The position of the peak(s) indicates the angular location of the flaw(s) and the amplitude of the signal, in millivolts, is proportional to flaw size. On detection, the display freezes and a digital readout of the maximum peak value is displayed in the top right corner.

(1) QETE POD Specimens

Results of the inspections of the holes with countersink flaws are shown in Figure 6. The amplitude of Rivet Check signal (millivolts) versus known crack size (0.001") at each of four different depth settings is displayed. Flaws between 0.040" and 0.150" were detected readily and the resulting indication was proportional to flaw size. The system also correctly identified the relative position of the cracks. It was found that under these conditions the system was unable to detect cracks smaller than ~0.040". The presence of titanium rivets did not interfere with the ability to detect flaws, but the amplitude of the signal produced by the system was reduced by a factor of two.

Reliable detection of countersink flaws under the head of steel rivets was virtually impossible. It was very difficult to center the test head and the system did not automatically detect any flaws. Peaks on the display indicated that flaws were distributed randomly and not at their known locations. The interference caused by the presence of ferrous fasteners when inspecting using other eddy current devices has been observed in previous investigations (3).

Results of the inspections of the holes with surface flaws are shown in Figure 7. The amplitude of Rivet Check signal (millivolts) versus known crack size (0.001") at each of four different depth settings is displayed. Although results are more scattered than for the countersink flaws, cracks between 0.010" and 0.190" were detected readily and the resulting indication was proportional to flaw size. The system also correctly identified the relative position of the cracks. The presence of either titanium or ferrous rivets did not interfere with the ability to detect flaws, nor was the amplitude of the signals produced by the system affected appreciably. Generally, stronger signals were obtained when the system pre-set test depth was set to detect at the top surface. It should be noted that this observation does not contradict the above result. The previous inspection attempted to detect flaws underneath the 0.5" fastener head. In the present case the flaws were located adjacent to, not under, ferrous material.

Results of the inspections of the holes with mid-bore flaws are shown in Figure 8. The amplitude of Rivet Check signal (millivolts) versus known crack size (0.001") at each of four different depth settings is displayed. Again, results are more scattered than for the countersink flaws and the amplitude of the signals produced was significantly weaker than for the both surface and countersink flaws. Cracks between 0.045" and 0.175" were detected readily and generally, the resulting indication was proportional to flaw size. The system also correctly identified the relative position of the cracks. The presence of either titanium or ferrous rivets did not interfere with the ability to detect flaws, nor was the amplitude of the signal produced by the system affected appreciably. Because the flaws were deeper, overall amplitude was less than for the surface flaws.

(2) Lap Joint Inspection

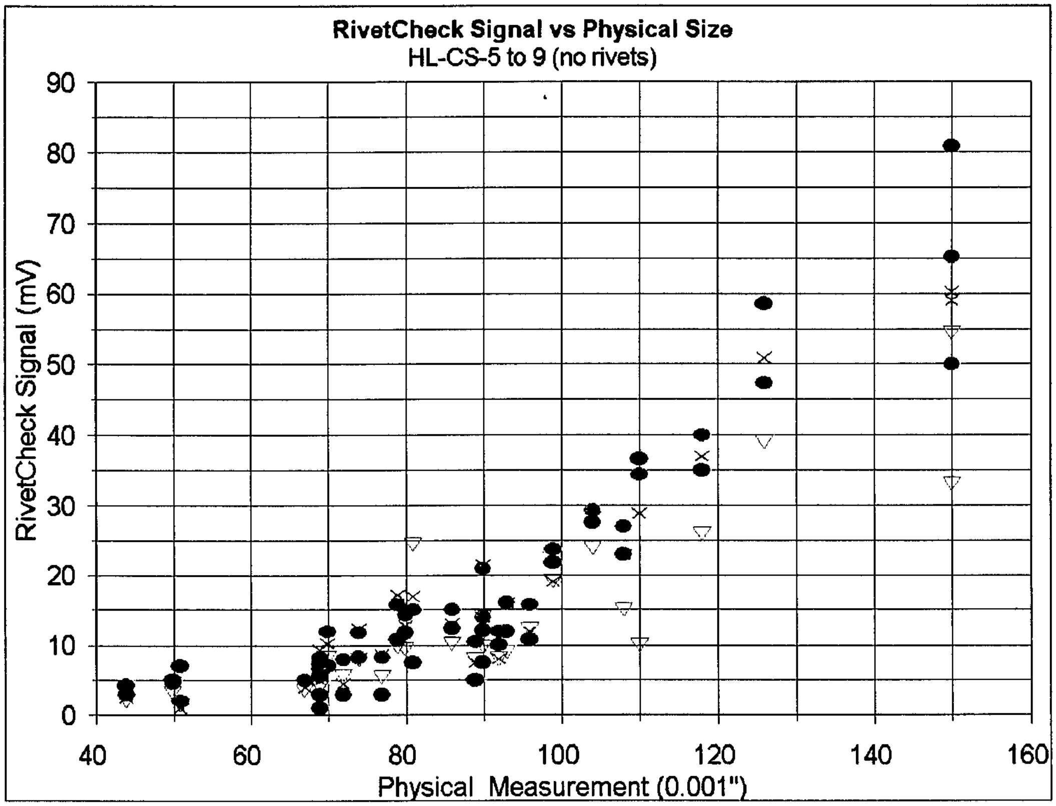
Each of the holes in specimen MSD 504 was inspected using the Rivet Check at each of its four depth settings. In the first row, signals were observed and flaws were automatically detected for all holes at each of the three lowest depth settings. No flaws were detected at the top surface setting. Signals from the unflawed holes were just above "noise" level, with the known flaws producing peaks at least twice as large. There were no flaw indications for any of the holes in the second row - the inspections produced essentially flat signals. Very strong indications were received from the flaws in the third row holes at each of the four depth settings and their positions were correctly indicated as shown in Fig 4 (i.e. a flaw on each side of each of the center holes approximately 180° apart, and only one flaw for each of the end holes). The amplitudes of these signals were more than an order of magnitude larger than those from the second layer cracks.

Practical

The Rivet Check system was made available to and was used by personnel at the Canadian Forces' Aerospace and Telecommunications Engineering Support Squadron and at Bombardier Aerospace, the maintenance contractor for the CF-18 fighter. It was agreed that the Rivet Check system was easy to use and successfully detected flaws in laboratory test coupons. The ability to store test results was an advantage. It was felt that while the system was suitable for flat surfaces, there were often real situations where surface curvature would prevent positioning the test head close enough to the rivets to be inspected (e.g. station 470.5 of the CF-18 dorsal crease longeron). It was also felt that for field use, especially under cool conditions, the umbilical cable should be more flexible. The adjustments for both liftoff and test depth, currently made using a small screwdriver, should be larger and easier to access, again particularly for field use.

Conclusions

It was found that the Foerster Rivet Check system is able to detect relatively small cracks under installed non-ferrous fasteners at depths up to 0.12" in layers of aircraft skin. The amplitude of its' output signal is proportional to flaw size and it is able to indicate the relative position of flaws. Interference from the presence of ferrous fasteners results in false indications. At present the system works well in the laboratory on flat surfaces, but modifications are required to make it more suitable for use under field conditions.



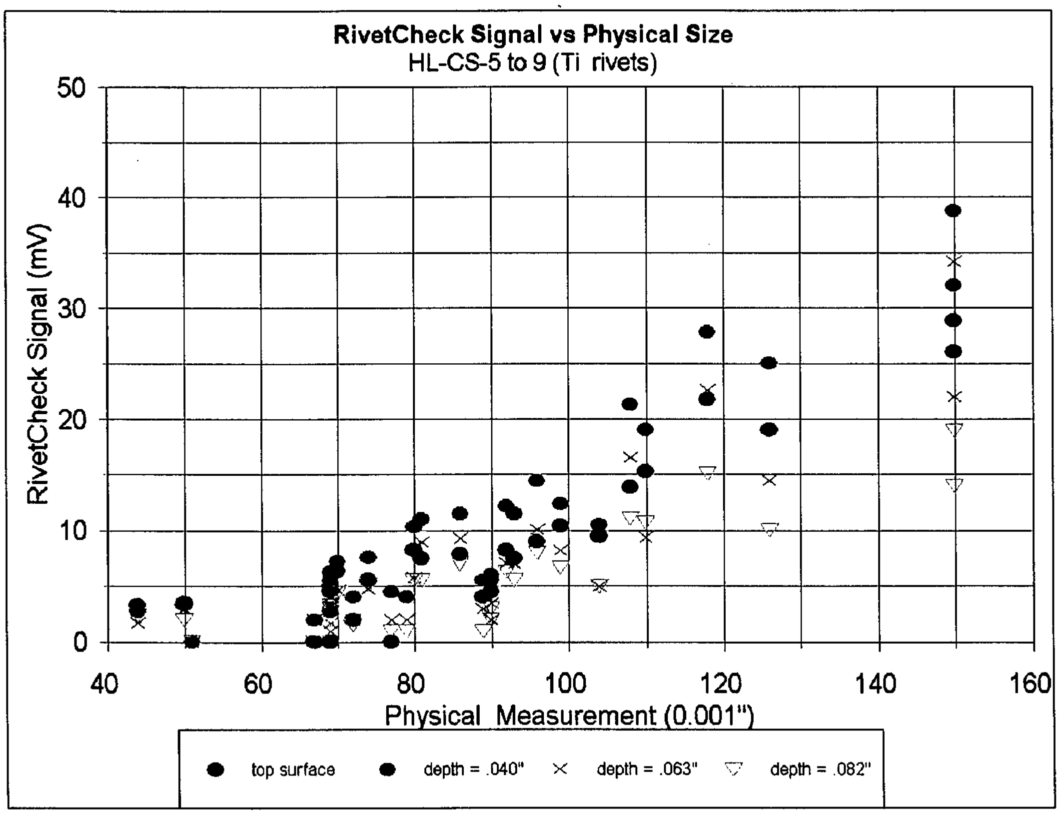


Figure 6 - Rivet Check Signal vs Flaw Size With and Without Titanium Fasteners: Countersink Flaws

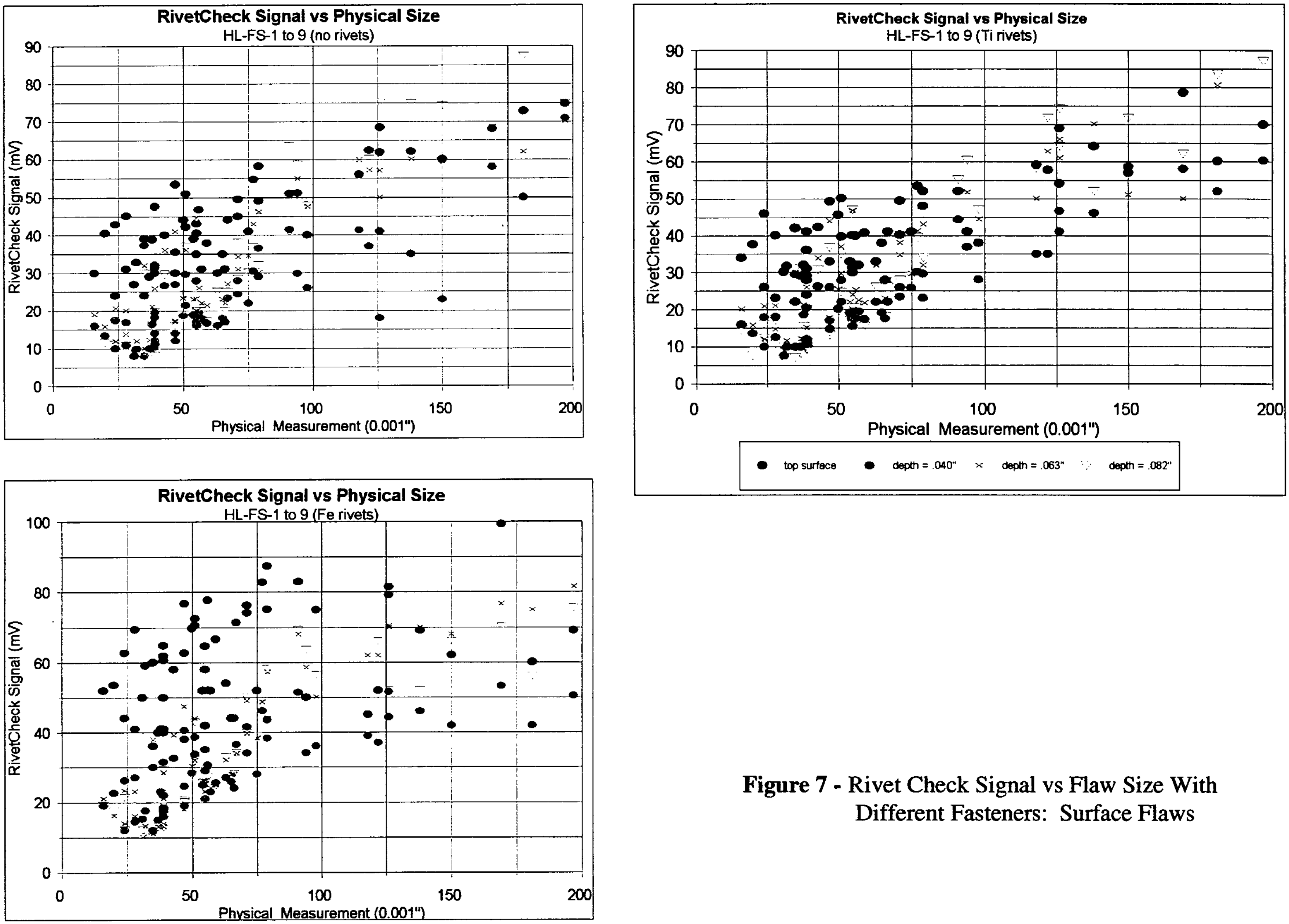


Figure 7 - Rivet Check Signal vs Flaw Size With Different Fasteners: Surface Flaws

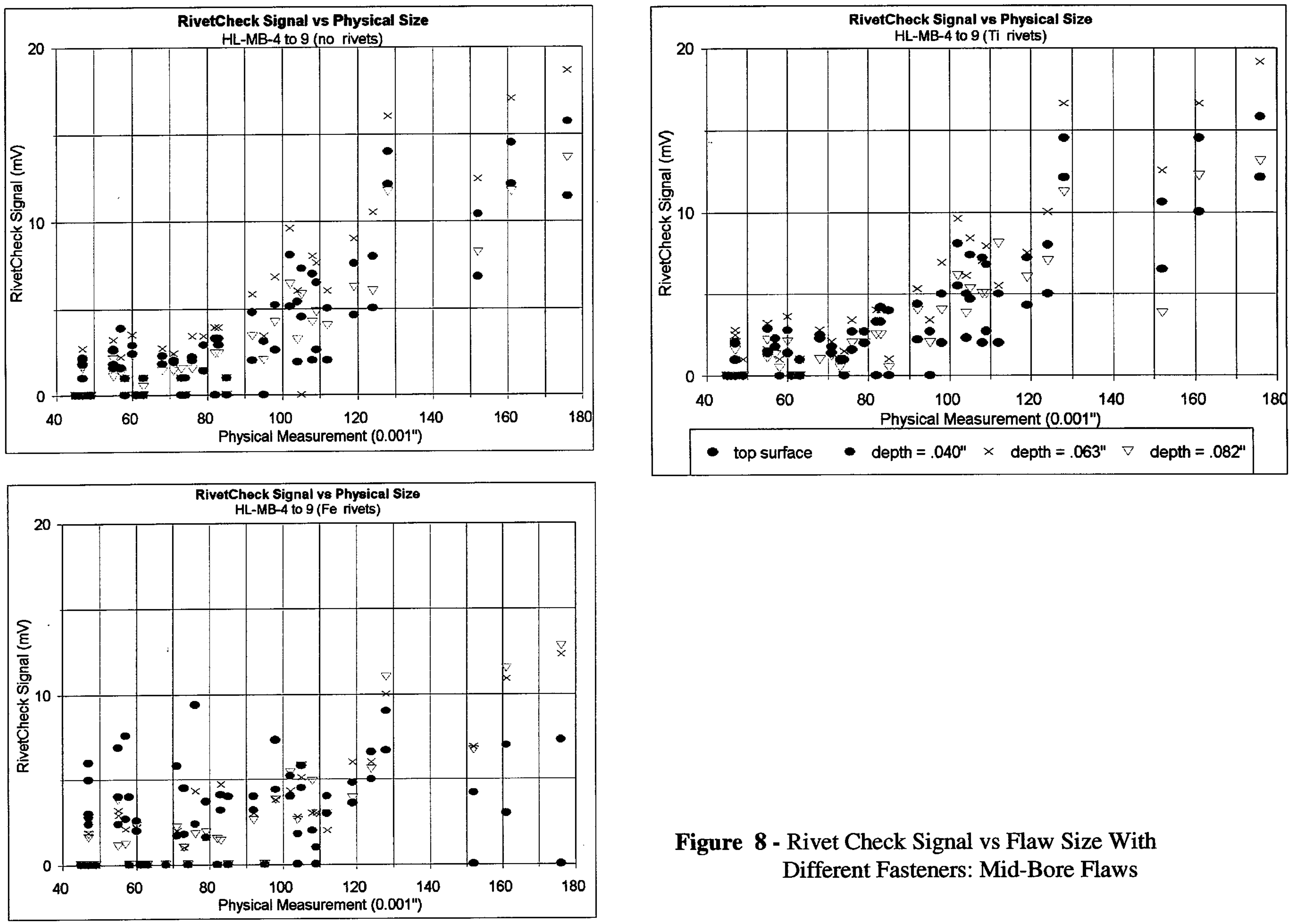


Figure 8 - Rivet Check Signal vs Flaw Size With Different Fasteners: Mid-Bore Flaws

References

1. Rivet Check 2.839 Operating Instructions, Foerster Instruments Incorporated, 140 Industry Drive, RIDC Park West, Pittsburg, PA 15275-1028
2. CF116 Upper Wing Skin Golden Triangle POD Specimens, QETE Project Number A013692, December 1993
3. R.W. Nolan and K.I. McRae, "Detecting Cracks Under Ferrous Fasteners Using the Nortec-30 Eddyscan Fastener Hole Inspection Instrument", DCIEM No. 97-TM-12, February 1997

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Fatigue cracks
Cracks under fasteners
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Ferrous fasteners
Foerster Rivet Check